Apr 30th, 1:00 PM

Paper Session III-B - Prospects of utilization of the space-purpose temperature sensors for public and commercial use

Yu M. Shwartz
Institute of Semiconductor Physics, National Academy of Sciences of Ukraine

E. F. Venger
Institute of Semiconductor Physics, National Academy of Sciences of Ukraine

N. R. Kulish
Institute of Semiconductor Physics, National Academy of Sciences of Ukraine

V. L. Borblik
Institute of Semiconductor Physics, National Academy of Sciences of Ukraine

Prospects of utilization of the space-purpose temperature sensors for public and commercial use

Yu. M. Shwarts, E.F. Venger, N.R. Kulish, V.L. Borblik

Institute of Semiconductor Physics, National Academy of Sciences
of Ukraine, Prospect Nauki 45, 252650 Kiev, Ukraine
E-mail: zinovi@lab2.kiev.ua
FAX # (044) 265-83-42, 265-23-20
Phone # (044) 265-56-70

Introduction

For the temperature monitoring of units, mechanisms and technological manufacture processes use of sensors which convert temperature to electric signal is preferable. Metal and semiconductor resistance thermometers, thermocouples and thermodiodes are such sensors. Comparative characteristics of these sensors are given in Tab. 1.

Temperature ranges which are subject to monitoring and control in a number of the most important branches of engineering are represented by Tab. 2. Comparison of these data shows that in majority of cases temperature has to be measured in the range of 190 ÷ 450 K. It appears that thermodiode sensors are the most suitable for this purpose because they are superior to all other sensors in sensitivity, output signal level, cost and simplicity of use. Their salient feature is the possibility of connection with the measuring unit by means of two-wire connection line of length from some tens meters to some kilometers.

Principle of action of the diode temperature sensor

Thermodiode sensor is Ge, Si or GaAs p-n junction diode in which leakage current is minimized and thermal path from environment to p-n junction is optimized. The latter condition is achieved by location of diode in specialized package.

When constant direct current flows through the diode in forward direction (plus to p-region, minus to n- region) the voltage drop U across the diode is

$$\mathbf{U = kT/q \ln[(I/I_s) + 1],} \qquad \mathbf{(1)}$$

where $\mathbf{I}$ and $\mathbf{I_s}$ - operating and saturation current respectively; the latter is given by

$$\mathbf{I_s = A(T^{\nu}/N_a\tau_n{}^{1/2})\exp(-E_g/kT),} \qquad \mathbf{(2)}$$

where $\mathbf{N_a}$ - acceptor concentration, τ_n - electron lifetime in diode base, $\mathbf{E_g}$ - energy gap, $\mathbf{A}$, ν - constants. Usually $\mathbf{I} >> \mathbf{I_s}$; herewith Eq. (1) becomes

Tab. 1

Comparative characteristics of different temperature sensors

Sensor type	Temperature range to be measured, K	Advantages	Disadvantages
Metal resistance thermometer	15-1300	Small error (<0.5 K), interchangeability (shift of 1 K), service life > 50 000 hours	Large response time (8 s)
Semiconductor resistance thermometer	0.1 - 300	Large sensitivity (4×10^{-2} V/K) in low temperature range	Poor interchangeability, narrow temperature range, small sensitivity in high temperature range
Thermocouple	1-3800	Small error (0.1-10 K), service life > 50 000 hours	Necessity for supporting of stable temperature of second junction, small sensitivity
Thermodiode	4-500	Large sensitivity (2×10^{-3} V/K), batch production	Degradation at high temperatures (> 500 K)

Tab. 2.

Ranges of temperature and mechanical exposures

Subject type	Bounds of the temperature range, K		Vibration	
	Lower	Upper	Frequency, Hz	Amplitude, mm
External environment	210	330		
Stationary mechanisms	190	400	50-400	0.15
Vehicles	190	330	400 - 7 000	0.05
Aircraft and cosmonauts	190	620	5 - 150	0.15 - 5

$$U(T) = E_g/q + (kT/q)\ln(I\, N_a \tau_n^{\ 1/2} / AT^{\nu}), \qquad (3)$$

i.e. **U(T)** is nearly linear function.

Principal characteristics

Typical performance of our base temperature sensors are represented by Tab. 3. In this table parameters of similar sensors produced by Lake Shore Cryotronics, Inc. are also given for comparison. Our sensors are on a par with the Lake Shore's ones and have even some advantages.

Tab. 3

Comparative data as to parameters of our sensors and sensors produced by Lake Shore Cryotronics, Inc. (USA) [1]

Parameter	Institute of Semicond. Phys., National Academy of Sciences, Ukraine	Lake Shore Cryotronics, Inc., USA, (DT-470 SD)
Temperature range	77-500 K	77-475 K
Accuracy	±0.1 K	±0.15 K (60-345 K)
Operating current	100 μA (±0.05%)	10 μA (±0.05%)
Overall dimensions	2x2x2.5 mm^3	1x1.9x3.2 mm^3
Interchange tolerance	±0.5 K in all range	±1% of temperature
Cost	depending on sensor type but not more than $ 85	$ 485

At the Fig. 1 the temperature response curves (for 250 devices) and corresponding sensitivities of sensor are shown.

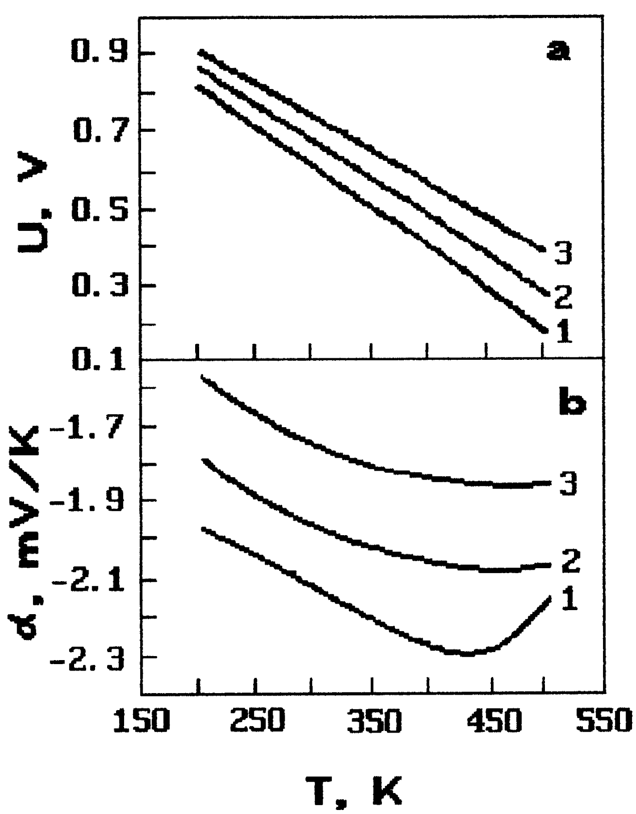

Fig 1. The typical temperature response curves (a) and sensitivities of sensor (b) at the different operating current,μA: 1 - 1, 2 -10, 3 - 100.

Effect of the long connection line

When thermodiode is connected to measuring unit by means of the long connection line the voltage drop registrated is equal, rigorously speaking, to sum of voltage drops across the diode $\mathbf{U_d}$ and across the line resistance $\mathbf{U_r}$

$$\mathbf{U = U_d + U_r = (kT/q)\ ln[(\ I/I_s) + 1)]\ + IR.} \qquad \mathbf{(4)}$$

Hence systematic error in temperature measuring introduced by two-wire line resistance is equal to

$$\mathbf{\Delta T = U_r/\alpha = IR/\alpha = I\rho_0(1+\beta\Delta t)\mathit{l}\ S\alpha,} \qquad \mathbf{(5)}$$

where α **= dU/dT -** sensitivity of sensor, ρ_0, β, l , **S -** resistivity (at 0° C), temperature resistivity coefficient, length and cross section of the metal two-wire line respectively, $\mathbf{\Delta t = t - 0\ ^\circ C}$**, t -** environment temperature in Celsius's degrees. The error given by Eq. (5) is proportional to the operating current and line resistance and varies inversely with the sensor sensitivity. Because the connection line is laid on terrain its temperature depends on 24 - hourly and seasonal variations of temperature . In the countries with temperate climatic conditions (Ukraine is just a such country) these temperature variations are in the limits $-50^\circ C \le \mathbf{t} \le 50^\circ C$ [2]. Sensitivity of the sensor does not depend on resistivity of the connection line, but it depends on temperature and operating current (see Fig. 1). For estimation of the maximal error of temperature measuring one has to substitute into Eq. (5) maximal value of **t** and minimal value of α.

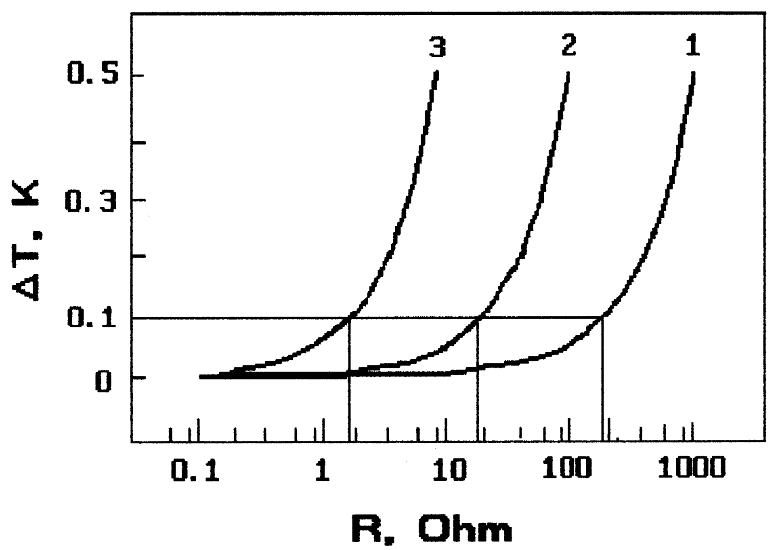

Fig. 2. The systematic error of temperature measuring Δ**T** versus connection line resistance **R** at the same values of operating current that in Fig.1.

Fig. 2 demonstrates the method for estimation of line resistance at the given value of systematic temperature error $\Delta\mathbf{T}$. This figure is a nomogram of systematic error versus resistance of the copper wire that is recommended for use in the long connection lines [2]. Using this nomogram one can find the maximal allowable distance **L** from the sensor to registrating apparatus (**L=l/**2) when error introduced by line is not in excess of the given value $\Delta\mathbf{T}$. The set of such estimation of **L** calculated for different operating currents and a number of cross section values at $\Delta\mathbf{T}$ = 0,1 K is given in Tab. 4.

Tab. 4

S, mm²	**L, m (I=1 μÀ)**	**L, m (I=10 μÀ)**	**L, m (I=100 μÀ)**
0.35	1806	181	18
0.7	3612	361	36
1.0	5160	516	52
1.5	7740	774	77
2.0	10320	1032	103

Fields of application

Performance of the our silicon temperature sensor represented by Tab. 3 are for the diode which is housed in the base package. For application to each specific case the base sensor has to be modified. Modification consists in location of silicon diode chip in the specialized package or housing of the base sensor as a whole in the package which properties are determined by requirements of specific branch of industry. In Tab. 5 we list briefly fields of application of our diode sensors in the industrial conditions. Then we describe in some detail the results of using of the diode temperature sensors for temperature monitoring in different points of the heat power station [3].

Tab. 5

Before installation of the diode thermometers to the testing points of the heat power station

Field of application	**Temperature range, °C**	**Measuring error,°C**	**Term of testing, days**
Temperature monitoring of turbine bearings at the atomic power stations of Ukraine.	**+20...+90**	**±0.5**	**500**
Temperature monitoring of rotate mechanism bearings at the wind power station of Ukraine.	**-50...+90**	**±0.5**	**180**
Temperature monitoring of drilling solution at the gas wells of Ukraine.	**-30...+100**	**±0.5**	**720**
Temperature monitoring of baking bread.	**+20...+150**	**±0.5**	**1000**
Temperature monitoring of plastic products.	**+20...+200**	**±1**	**900**
Temperature monitoring of man's body.	**+20...+50**	**±0.05**	**200**

(in Ukraine) we have determined (at the testing benches of design office “Yuzhnoje”) additional errors which are introduced as a result of action of the next factors:

mechanical shocks with amplitude of 1000 m/s^2 and duration of 5 ms;

linear accelerations with amplitude of 150 m/s^2;

humidity of 98 % at the room temperature of 25^0 C;

relieved atmospheric pressure of 5×10^{-2} mm mercury;

vibration with acceleration amplitude from 20 to 240 m/s^2 in the frequency range from 20 to 2 000 Hz; duration of action - 180 s.

The additional error from all investigated factors is not in excess of main error value equal to 0.5 K.

By means of the diode thermometers the next parameters at the heat power station were monitored:

temperature of gas going away in smoke-exhauster;

temperature of steam in the 8th turbine bleed;

temperature of nutritious water;

temperature of the front bearing of the electromotor;

temperature of the front and back pump bearings.

After 240 days of operation our sensors have been recalibrated. Maximal deviation from initial temperature response curve was not in excess of 0.01 - 0.05^0 C in the temperature range 20 - 200^0 C.

Conclusion

Performance of all sensors converting temperature into electric signal, exept for thermodiodes, are close to their limit values. As to thermodiodes one can claim that they may yet be improved considerably. As far as thermodiode sensors will being improved, their field of application will expand, reliability will increase and cost will decrease.

This work has fulfilled within the scope of scientific program of National Space Agency of Ukraine and partially under financial support of Science and Technology Center in Ukraine (project N 477).

Referencies

1. Temperature measurement and control. 1995, part 1 of 2. - Lake Shore Cryotronics, Inc., USA, 1995.

2. Kratkii spravochnik konstruktora radioelektronnoi apparatury / Edit. by R. G. Varlamov, - Moscow, “Sov. radio”, 1973 (in Russian).

3. Yu. M. Shwarts, E. F. Venger, A. G. Kundzich et al. Energetika i elektrifikatsiya, 1997, N 2, p. p. 3 - 7 (in Russian).